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OBSERVATIONS OF MARS WITH THE PHOTOGRAPHIC ZENITH TUBE

ALICE K. BABCOCK
U. S. Naval Observatory, Washington, D. C. 20390
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ABSTRACT

Observations of Mars with a photographic zenith tube during the oppositions of 1975 and 1978 are described. A brief review of the reduction procedure is given. Analysis is made of the effects of chromatic aberration and ephemeris errors. Possible uses are suggested for the results of this analysis in further research.

I. INTRODUCTION

The planet Mars was observed near the times of its two most recent oppositions, 15 December 1975 and 22 January 1978, by the photographic zenith tube (PZT) at the U. S. Naval Observatory Time Service Substation in Richmond, Florida. This instrument has a field of view 34 arcmin in diameter, and can observe objects with declinations between 25°20′ and 25° 54′. Mars appeared within its field of view from 25 November to 7 December 1975, from 5 January to 7 March 1976, and from 23 to 27 February 1978. Over these three periods, 65 observations were made of the planet. Positions of Mars obtained from the PZT observations were compared with an improved Mars ephemeris, prepared by the Nautical Almanac Office of the U. S. Naval Observatory (Kaplan 1978). It was hoped this comparison would lead to an understanding of chromatic aberration in the PZT lens and systematic errors in the Mars ephemeris.

II. OBSERVATIONS

Mars was photographed by the standard technique for PZT observations (Markowitz 1960), with one difference. An objective grating was introduced during observations of the planet in order to reduce magnitude effects. The grating consists of three layers of plastic screening, oriented at 60° with respect to each other, with squares 1.67 ± 0.20 mm wide and wires 0.385 ± 0.025 mm thick. There are approximately 6 squares/cm, and the grating is 216 mm in diameter, fully covering the 200-mm PZT objective. The equivalent focal length of the instrument is 3786 mm, resulting in a plate scale of about 54 arcsec/mm. The photographic plates are 45 mm^2 and have Kodak Spectrum Analysis 3 emulsion.

Stars on the regular Richmond observing list (McCarthy 1977) were photographed on the same plates as Mars. Stars on each plate were used to determine the plate constants, by the standard method (McCarthy 1970). The plate constants then entered into the reduction of the Mars observations, so that positions found for the planet are referred to the current Richmond PZT catalog. This catalog agrees with FK4 to ±0ˢ004 in right ascension and ±0.03 arc sec in declination.

All the plates taken by the Richmond PZT were measured at the Richmond station. Mars observations for 1975 and 1976 were measured on the Gaertner comparator, and those for 1978 on the Boller & Chivens microdensitometer. For all except the last three observations, positions of the images of Mars were measured by visual bisection. The last three observations were measured automatically with a multiple-scan software routine developed by the staff at Richmond. Although Mars was moving during the observations, the exposure time of 23 s was sufficiently short so that images of the planet appeared round on the plates.

III. REDUCTION

Positions derived from the observations were corrected for defect of illumination, and then compared to the positions obtained from the new Mars ephemeris. Predicted positions of Mars, at the times of transit for each observation, are listed in Table I. Also listed are the residuals representing observations minus predictions. The last column of Table I contains observed zenith distances of Mars, given in seconds of arc. The ephemeris used to calculate transit times and positions is based on the work of Laubscher (1971), as corrected by Kaplan (1978). The residuals were examined for evidence of chromatic aberration and ephemeris errors.

Theoretical analysis of the PZT at Neuchatel (Schuler 1967) indicated that chromatic aberration could be a significant source of error in the measurement of zenith distance. The magnitude of the error would be directly proportional to the zenith distance of the object observed. The declination of an object on the meridian is the difference between the astronomical latitude of the observer and the zenith distance of the object. Therefore, chromatic aberration would be expected to lead to a correlation between declination residuals and zenith distances. Chromatic aberration is not expected to affect results in right ascension. Furthermore, since proper motions in the PZT catalog have been determined internally (McCarthy 1973), chromatic aberration in the PZT lens

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TABLE I. Predicted and observed positions of Mars at transit times.

DATE			PREDICTED POSITIONS DECLINATION	PREDICTED POSITIONS RT.ASCENSION	(C-P)C	OBSERVED - PREDICTED M.E.	OBSERVED - PREDICTED (O-P)RA	M.E.	OBSERVED ZENITH DIST.
YR	MO	DA	° ′ ″	H M S	″	″	S	S	″
75	11	25	25 21 10.95	6 0 33.71	-0.362	0.131	-0.4684	0.0156	936.48
75	11	27	25 27 7.40	5 58 6.77	-0.102	0.206	-0.4474	0.0116	579.88
75	11	28	25 30 0.27	5 56 48.49	0.139	0.177	-0.4717	0.0175	406.77
75	11	29	25 32 48.86	5 55 27.19	0.022	0.132	-0.4957	0.0102	238.22
75	11	30	25 35 32.72	5 54 3.00	0.369	0.102	-0.4173	0.0093	74.00
75	12	1	25 38 11.31	5 52 36.07	0.699	0.193	-0.4993	0.0140	-84.88
75	12	2	25 40 44.18	5 51 6.57	0.368	0.187	-0.4701	0.0111	-237.44
75	12	3	25 43 10.74	5 49 34.68	0.631	0.100	-0.5000	0.0106	-384.10
75	12	4	25 45 30.65	5 48 0.59	0.579	0.099	-0.4744	0.0090	-523.94
75	12	5	25 47 43.42	5 46 24.50	0.888	0.108	-0.4883	0.0093	-657.16
75	12	7	25 51 46.27	5 43 7.12	0.536	0.185	-0.4525	0.0159	-899.65
76	1	5	25 52 59.99	4 59 24.85	0.737	0.162	-0.0185	0.0112	-973.46
76	1	6	25 51 55.01	4 58 30.61	0.612	0.117	-0.0367	0.0102	-908.38
76	1	7	25 50 50.13	4 57 39.95	0.936	0.205	-0.0810	0.0162	-843.80
76	1	11	25 46 39.76	4 54 53.59	0.641	0.116	-0.0245	0.0079	-593.21
76	1	12	25 45 41.25	4 54 21.12	0.689	0.211	-0.0477	0.0159	-534.69
76	1	13	25 44 44.95	4 53 52.30	0.421	0.137	-0.0516	0.0122	-478.15
76	1	15	25 42 59.97	4 53 5.50	0.881	0.277	-0.0641	0.0136	-373.55
76	1	16	25 42 11.74	4 52 47.46	0.242	0.223	-0.0553	0.0182	-324.83
76	1	17	25 41 26.54	4 52 32.97	0.290	0.185	-0.0359	0.0122	-279.66
76	1	18	25 40 44.57	4 52 21.97	0.274	0.093	-0.0545	0.0123	-237.52
76	1	19	25 40 5.90	4 52 14.43	0.340	0.120	-0.0303	0.0131	-198.91
76	1	22	25 38 30.26	4 52 12.17	0.230	0.101	-0.0591	0.0119	-103.15
76	1	23	25 38 5.32	4 52 18.08	0.761	0.181	-0.0376	0.0184	-78.77
76	1	24	25 37 43.90	4 52 27.25	0.338	0.170	-0.0662	0.0160	-56.94
76	1	25	25 37 25.99	4 52 39.64	0.489	0.196	-0.0715	0.0149	-39.19
76	1	26	25 37 11.60	4 52 55.21	0.053	0.122	-0.0242	0.0083	-24.39
76	1	27	25 37 0.61	4 53 13.91	0.089	0.100	-0.0496	0.0108	-13.43
76	1	29	25 36 48.91	4 54 0.52	0.144	0.118	-0.0635	0.0091	-1.64
76	1	30	25 36 48.03	4 54 28.34	0.216	0.168	-0.0568	0.0132	-0.95
76	1	31	25 36 50.28	4 54 59.09	0.086	0.234	-0.0515	0.0142	-3.27
76	2	1	25 36 55.56	4 55 32.75	0.130	0.137	-0.0362	0.0099	-8.51
76	2	2	25 37 3.80	4 56 9.23	0.249	0.120	-0.0480	0.0078	-16.85
76	2	3	25 37 14.84	4 56 48.50	0.156	0.260	-0.0280	0.0127	-27.61
76	2	4	25 37 28.57	4 57 30.50	0.398	0.188	-0.0659	0.0146	-41.64
76	2	5	25 37 44.83	4 58 15.18	0.346	0.124	-0.0300	0.0134	-57.92
76	2	6	25 38 3.45	4 59 2.47	0.218	0.158	-0.0518	0.0118	-76.34
76	2	8	25 38 47.23	5 0 44.68	0.278	0.100	-0.0323	0.0107	-120.21
76	2	9	25 39 12.06	5 1 39.48	0.395	0.133	-0.0945	0.0115	-145.11
76	2	10	25 39 38.54	5 2 36.68	0.005	0.149	-0.0299	0.0094	-171.08
76	2	11	25 40 6.61	5 3 36.21	0.317	0.242	0.4187	0.0168	-199.64
76	2	12	25 40 36.00	5 4 38.01	0.465	0.192	0.4344	0.0144	-229.16
76	2	13	25 41 6.60	5 5 42.04	0.281	0.193	0.4683	0.0130	-259.40
76	2	14	25 41 38.13	5 6 48.22	0.397	0.208	0.4662	0.0177	-291.15
76	2	15	25 42 10.37	5 7 56.52	0.684	0.191	0.4621	0.0127	-323.67
76	2	16	25 42 43.17	5 9 6.87	0.381	0.171	0.4305	0.0162	-356.26
76	2	18	25 43 49.52	5 11 33.54	0.200	0.100	0.4500	0.0094	-422.45
76	2	19	25 44 22.65	5 12 49.77	0.175	0.174	0.4633	0.0102	-455.62
76	2	21	25 45 27.96	5 15 27.84	0.095	0.126	0.4661	0.0104	-520.76
76	2	22	25 45 59.66	5 16 49.59	0.468	0.083	0.4510	0.0078	-552.80
76	2	23	25 46 30.58	5 18 13.10	0.684	0.211	0.4787	0.0168	-584.09
76	2	24	25 47 0.41	5 19 38.35	0.586	0.144	0.4871	0.0093	-613.62
76	2	29	25 49 7.14	5 27 9.19	0.650	0.166	0.4608	0.0129	-740.45
76	3	1	25 49 26.64	5 28 44.03	0.454	0.153	0.5001	0.0113	-759.82
76	3	2	25 49 43.83	5 30 20.35	0.536	0.134	-0.0728	0.0101	-777.02
76	3	3	25 49 58.44	5 31 58.11	0.573	0.147	-0.2956	0.0078	-791.78
76	3	4	25 50 10.31	5 33 37.29	0.538	0.123	-0.0404	0.0098	-803.51
76	3	5	25 50 19.32	5 35 17.83	0.665	0.083	-0.0646	0.0098	-812.65
76	3	6	25 50 25.25	5 36 59.71	0.770	0.112	-0.0401	0.0084	-818.73
76	3	7	25 50 28.00	5 38 42.89	0.901	0.176	-0.0353	0.0141	-821.51
78	2	23	25 24 26.73	7 40 30.80	0.142	0.089	-0.0203	0.0115	740.16
78	2	24	25 23 29.77	7 40 6.93	0.096	0.142	-0.0389	0.0104	797.02
78	2	25	25 22 23.68	7 39 46.42	0.229	0.103	-0.0335	0.0116	863.22
78	2	26	25 21 8.70	7 39 29.25	0.062	0.229	-0.0077	0.0137	938.13
78	2	27	25 19 45.04	7 39 15.41	0.128	0.176	-0.0222	0.0149	1021.83

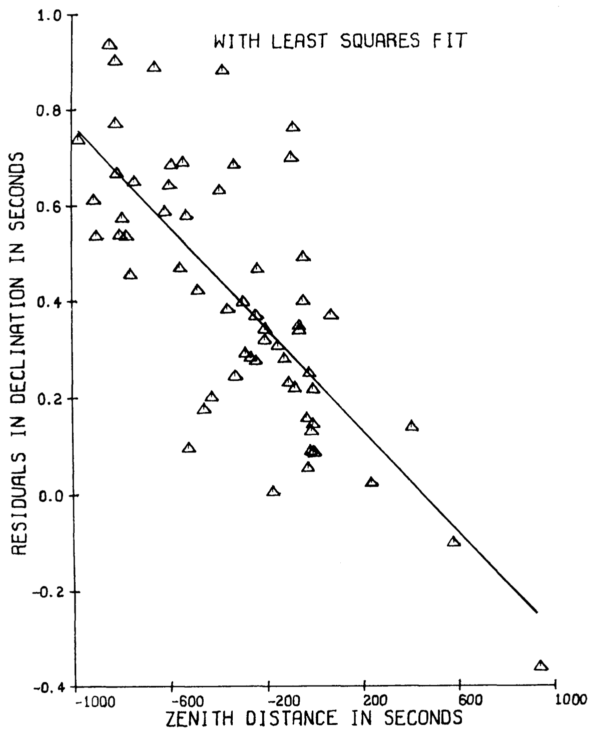

FIG. 1. Declination residuals versus zenith distance.

will lead to errors in catalog proper motions in declination. Theory indicates that such errors could be as large as ±1.″0/century (McCarthy 1969).

IV. RESULTS

When declination residuals are plotted against zenith distances (Fig. 1), there is a definite correlation. A linear regression fit to the data shows a slope of −0.0005 ± 0.0001. Such a correlation confirms a dependence on zenith distance, and suggests that chromatic aberration is responsible. The plot of declination residuals versus time (Fig. 2) also shows the correlation with zenith distance. When the proper motions of red PZT stars were adjusted for the apparent chromatic aberration, the corrections were on the order of 1.″0 century, in close agreement with the theory (Babcock 1978).

Figure 1 reveals evidence of an ephemeris error in that the intercept of the regression line does not equal zero. The intercept has a value of +0.″2392 ± 0.″0301. The most recent observations were not included in the calculation of the regression coefficients because the mean of their residuals differs significantly from the mean for the earlier observations. The two sets of observations represent different ephemeris corrections for the two epochs.

When the declination residuals are corrected for chromatic aberration and ephemeris errors, their plot versus time (Fig. 3) shows improved consistency. But the plot of right ascension residuals versus time (Fig. 4) is far from consistent. It exhibits an abrupt shift of about 0.ˢ09 across the time of opposition. This shift could not be attributed to ephemeris errors since these are generally slowly varying. Comparison of PZT residuals to those of the transit circle (Gauss 1978), for the same opposition, revealed a very similar shift. Investigation of this effect led to an unexpected finding.

The presence of an opposition or phase effect in visual observations of the brighter planets is discussed by Duncombe and Seidelmann (1978). The effect could result from the unequal brightness of the planetary limb and its terminator, before and after oppositions. The greater brightness of the illuminated limb weights the apparent position of the center of light in its direction. The magnitude of the error varies according to the individual observer, and thus enters into the personal equations. The presence of this effect has been well documented for visual observation. The PZT results for Mars indicate that it may be significant in photographic observations as well.

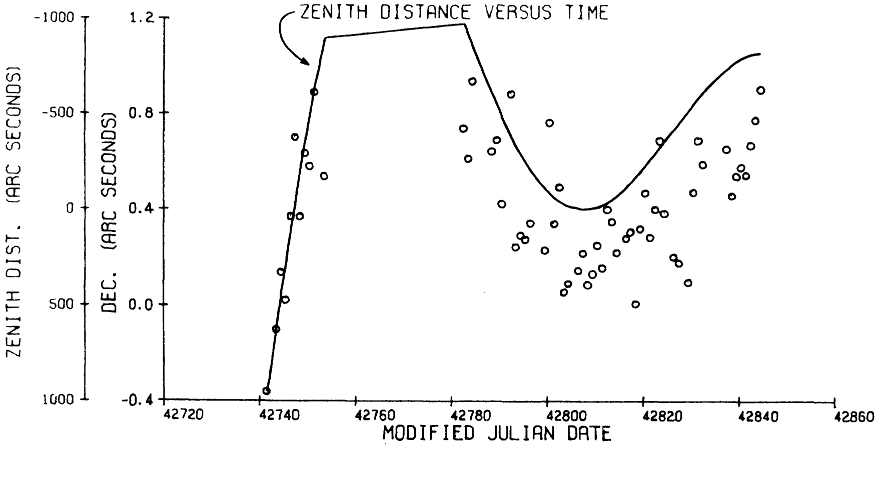

FIG. 2. Declination residuals versus time.

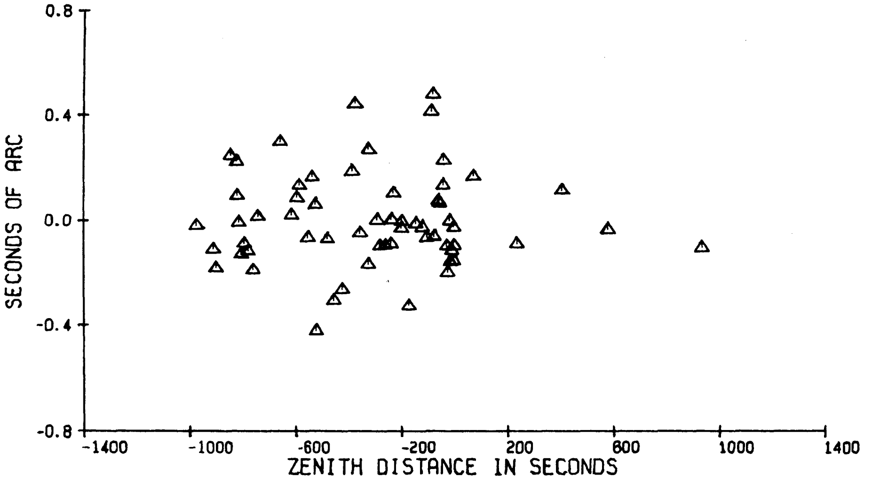

FIG. 3. Modified declination versus zenith distance.

V. CONCLUSION

There are three applications for the results of the PZT observations of Mars. They make it possible to quantify the effect of chromatic aberration. The proper motions of all stars in the PZT catalog with colors close to that of Mars, which has a $B - V$ magnitude of about $+1.41$ (Allen 1964), can now be corrected for this effect. There are more than 200 stars in the current catalog and over 10% of the proper motions may be corrected (Babcock 1978). The observations also indicate an error in the Mars ephemeris. Additional PZT observations of Mars are necessary to determine the characteristics of this error. Finally, the data indicate the presence of an opposition effect similar to that found in visual astrometric observations of the brighter planets. Quantification of this effect could be useful in future photographic determinations of planetary positions.

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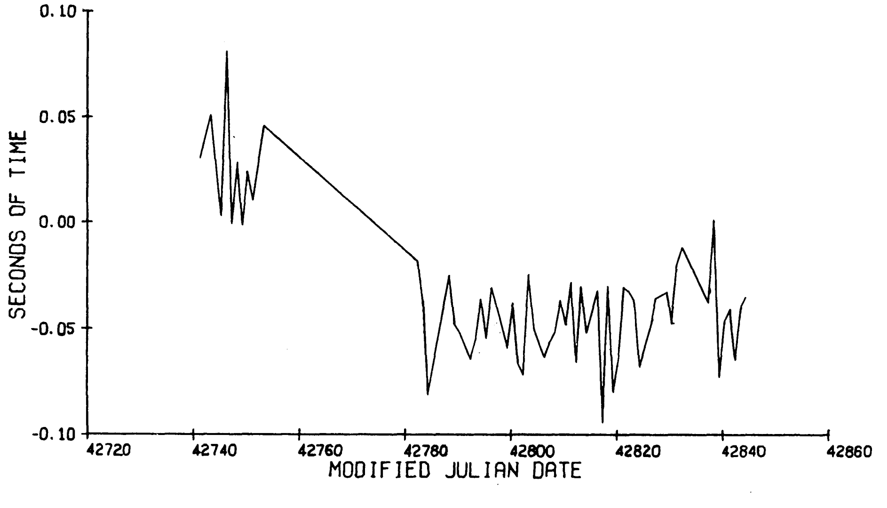

FIG. 4. Right ascension versus time.

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